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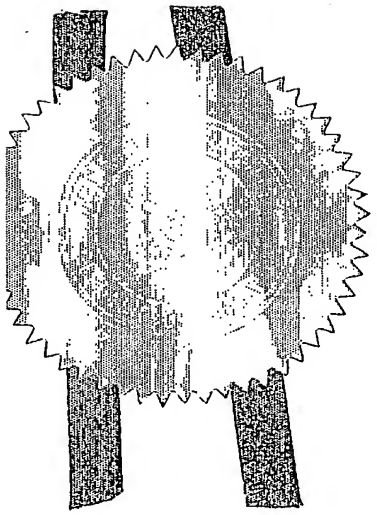
Date of Filing	:	03 JUN 2002
Application Number	:	200203275-3
Applicant(s) / Proprietor(s) of Patent	:	SENSFAB PTE LTD
Title of Invention	:	METHOD OF FORMING ATOMIC FORCE MICROSCOPE TIPS



Chig Kam Tack
Assistant Registrar
for REGISTRAR OF PATENTS
SINGAPORE

3 Jun 2003

G00001

PATENTS FORM 1
Patents Act
(Cap. 221)
Patents Rules
Rule 19

INTELLECTUAL PROPERTY OFFICE OF SINGAPORE

REQUEST FOR THE GRANT OF A PATENT UNDER SECTION 25

101101

* denotes mandatory fields

1. YOUR REFERENCE* MJ/LWC/cteo/PAT/8109400/SG

2. TITLE OF INVENTION* METHOD OF FORMING ATOMIC FORCE MICROSCOPE TIPS

3. DETAILS OF APPLICANT(S)* (see note 3) Number of applicant(s) 01

(A) Name SENSFAB PTE LTD

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#02-07 THE CAVENDISH
SINGAPORE 118259

State Country SG

[X] For corporate applicant [ ] For individual applicant

State of incorporation State of residency

Country of incorporation SINGAPORE Country of residency

[ ] For others (please specify in the box provided below)

(B) Name

Address

State Country

ACTION

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☐ For corporate applicant ☐ For individual applicant

State of incorporation | State of residency

Country of incorporation | Country of residency

☐ For others (please specify in the box provided below)

(C) Name

Address

State | Country

☐ For corporate applicant ☐ For individual applicant

State of incorporation | State of residency

Country of incorporation | Country of residency

☐ For others (please specify in the box provided below)

☐ Further applicants are to be indicated on continuation sheet 1

4. DECLARATION OF PRIORITY (see note 5)

A. Country/country designated

File number | Filing Date (DD MM YYYY)

B. Country/country designated

File number | Filing Date (DD MM YYYY)

☐ Further details are to be indicated on continuation sheet 6

5. INVENTOR(S)* (see note 6)

A. The applicant(s) is/are the sole/joint inventor(s) Yes ☐ No ☒

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B. A statement on Patents Form 8 is/will be furnished Yes [X] No [ ]

6. CLAIMING AN EARLIER FILING DATE UNDER (see note 7)

[ ] section 20(3) [ ] section 26(6) [ ] section 47(4)

Patent application number [ ]

DD MM YYYY

Filing Date [ ]

Please mark with a cross in the relevant checkbox provided below
(Note: Only one checkbox may be crossed.)

[ ] Proceedings under rule 27(1)(a)

DD MM YYYY

Date on which the earlier application was amended [ ]

[ ] Proceedings under rule 27(1)(b)

7. SECTION 14(4)(C) REQUIREMENTS (see note 8)

Invention has been displayed at an international exhibition. Yes [ ] No [X]

8. SECTION 114 REQUIREMENTS (see note 9)

The invention relates to and/or used a micro-organism deposited for the purposes of disclosure in accordance with section 114 with a depository authority under the Budapest Treaty.

Yes [ ] No [X]

9. CHECKLIST*

(A) The application consists of the following number of sheets

i.	Request	5	Sheets
ii.	Description	6	Sheets
iii.	Claim(s)	2	Sheets
iv.	Drawing(s)	2	Sheets
v.	Abstract (Note: The figure of the drawing, if any, should accompany the abstract)	1	Sheets
Total number of sheets		16	Sheets

(B) The application as filed is accompanied by:

[ ] Priority document(s) [ ] Translation of priority document(s)

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☐ Statement of inventorship & right to grant

☐ International exhibition certificate

10. DETAILS OF AGENT (see notes 10, 11 and 12)

Name

Firm DREW & NAPIER LLC

11. ADDRESS FOR SERVICE IN SINGAPORE* (see note 10)

Block/Hse No. | Level No. | Unit No./PO Box 152

Street Name ROBINSON ROAD

Building Name

Postal Code 900302

12. NAME, SIGNATURE AND DECLARATION (WHERE APPROPRIATE) OF APPLICANT OR AGENT* (see note 12)
(Note: Please cross the box below where appropriate.)

[X] I, the undersigned, do hereby declare that I have been duly authorised to act as representative, for the purposes of this application, on behalf of the applicant(s) named in paragraph 3 herein.

Name and Signature
(DREW & NAPIER LLC)

DD MM YYYY
31/05/2002

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NOTES:

1. This form when completed, should be brought or sent to the Registry of Patents together with the rest of the application. Please note that the filing fee should be furnished within the period prescribed.

2. The relevant checkboxes as indicated in bold should be marked with a cross where applicable.

3. Enter the name and address of each applicant in the spaces provided in paragraph 3.
Where the applicant is an individual
- Names of individuals should be indicated in full and the surname or family name should be underlined.
-The address of each individual should also be furnished in the space provided.
- The checkbox for "For individual applicant" should be marked with a cross.

Where the applicant is a body corporate
- Bodies corporate should be designated by their corporate name and country of incorporation and, where appropriate, the state of incorporation within that country should be entered where provided.
- The address of the body corporate should also be furnished in the space provided.
- The checkbox for "For corporate applicant" should be marked with a cross.

Where the applicant is a partnership
- The details of all partners must be provided. The name of each partner should be indicated in full and the surname or family name should be underlined.
- The address of each partner should also be furnished in the space provided.
- The checkbox for "For others" should be marked with a cross and the name and address of the partnership should be indicated in the box provided.

4. In the field for "Country", please refer to the standard list of country codes made available by the Registry of Patents and enter the country code corresponding to the country in question.

5. The declaration of priority in paragraph 4 should state the date of the previous filing, the country in which it was made, and indicate the file number, if available. Where the application relied upon in an International Application or a regional patent application e.g. European patent application, one of the countries designated in that application [being one falling under section 17 of the Patents Act] should be identified and the country should be entered in the space provided.

6. Where the applicant or applicants is/are the sole inventor or the joint inventors, paragraph 5 should be completed by marking with a cross the 'YES' checkbox in the declaration (A) and the 'NO' checkbox in the alternative statement (B). Where this is not the case, the 'NO' checkbox in declaration (A) should be marked with a cross and a statement will be required to be filed on Patents Form 8.

7. When an application is made by virtue of section 20(3), 26(6) or 47(4), the appropriate section should be identified in paragraph 6 and the number of the earlier application or any patent granted thereon identified. Applicants proceeding under section 26(6) should identify which provision in rule 27 they are proceeding under. If the applicants are proceeding under rule 27(1)(a), they should also indicate the date on which the earlier application was amended.

8. Where the applicant wishes an earlier disclosure of the invention by him at an International Exhibition to be disregarded in accordance with section 14(4)(c), then the 'YES' checkbox at paragraph 7 should be marked with a cross. Otherwise, the 'NO' checkbox should be marked with a cross.

9. Where in disclosing the invention the application refers to one or more micro-organisms deposited with a depository authority under the Budapest Treaty, then the 'YES' checkbox at paragraph 8 should be marked with a cross. Otherwise, the 'NO' checkbox should be marked with a cross. Attention is also drawn to the Fourth Schedule of the Patents Rules.

10. Where an agent is appointed, the fields for "DETAILS OF AGENT" and "ADDRESS FOR SERVICE IN SINGAPORE" should be completed and they should be the same as those found in the corresponding Patents Form 41. In the event where no agent is appointed, the field for "ADDRESS FOR SERVICE IN SINGAPORE" should be completed, leaving the field for "DETAILS OF AGENT" blank.

11. In the event where an individual is appointed as an agent, the sub-field "Name" under "DETAILS OF AGENT" must be completed by entering the full name of the individual. The sub-field "Firm" may be left blank. In the event where a partnership/body corporate is appointed as an agent, the sub-field "Firm" under "DETAILS OF AGENT" must be completed by entering the name of the partnership/body corporate. The sub-field "Name" may be left blank.

12. Attention is drawn to sections 104 and 105 of the Patents Act, rules 90 and 105 of the Patents Rules, and the Patents (Patent Agents) Rules 2001.

13. Applicants resident in Singapore are reminded that if the Registry of Patents considers that an application contains information the publication of which might be prejudicial to the defence of Singapore or the safety of the public, it may prohibit or restrict its publication or communication. Any person resident in Singapore and wishing to apply for patent protection in other countries must first obtain permission from the Singapore Registry of Patents unless they have already applied for a patent for the same invention in Singapore. In the latter case, no application should be made overseas until at least 2 months after the application has been filed in Singapore, and unless no directions had been issued under section 33 by the Registrar or such directions have been revoked. Attention is drawn to sections 33 and 34 of the Patents Act.

14. If the space provided in the patents form is not enough, the additional information should be entered in the relevant continuation sheet. Please note that the continuation sheets need not be filed with the Registry of Patents if they are not used.

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METHOD OF FORMING ATOMIC FORCE MICROSCOPE TIPS

FIELD OF INVENTION

The invention relates to atomic force microscope tips and more particularly for a method of forming silicon atomic force microscope tips using etching techniques.

BACKGROUND

Atomic force microscope tips are used to measure the topography of surfaces at an atomic level. In atomic force microscopy an atomic tip is scanned over a surface and the interactions between the few atoms at the end of the tip and the surface are recorded. The sharpness of the tip, or its radius of curvature, determines the resolution of the scan. Some atomic force microscope tips are formed at the edge of a cantilever. With cantilevered atomic force microscope tips the motion of the cantilever may be recorded to determine the topography of the surface being scanned. Atomic force microscopy may also be used in the manufacture of integrated circuits (IC) to measure the dimensions of components on the IC. There are also developments of applications for atomic force microscopy in the area of data storage. In this application shaper tips will enable a higher data density to be achieved since more data bits can be written per square area.

One method for forming atomic force microscope tips uses conventional electron beam chemical vapour deposition (CVD). This method as described in US patent 5,611,942 involves first forming a rounded tip. Masks are then added to the tip in areas where points will be formed. The mask covered tip is then etched for a predetermined period of time. The etching process removes the tip material in a parabolic manner between the masks leaving points under the mask layers. Finally the mask layer is removed to reveal a multi-pointed atomic force microscope tip. One problem with this method is ensuring uniformity of the etching process to form uniform tips. A further problem is that the tips tend to break off before they are sharp, leaving a fractured end.

Another method for forming atomic force microscope tips is to etch pyramidal pits into silicon with an etchant such as potassium hydroxide (KOH). These pits are then used as a mould for a silicon nitride tip. Common materials deposited in the mould include polymers, silicon dioxide and silicon nitride. Any moulded tip formed in this manner must be separated from the mould. In addition to the difficulty in ensuring a clean separation of the tips from the moulds, this method may not be applicable to more complex types of MEMS (microelectromechanical) structures. Further to this tips formed from silicon have superior physical properties, such as high strength and stiffness, when compared to tips formed from other materials.

SUMMARY OF INVENTION

It is the object of the invention to provide a method for forming atomic force microscope tips in silicon that overcome the disadvantages mentioned above or to at least provide the public with a useful choice.

In broad terms the invention comprises a method for forming a silicon atomic force microscope tip including the steps of depositing a masking layer onto a first layer of doped silicon so that some square or rectangular areas of the first layer of doped silicon are not covered by the masking layer, etching pyramidal apertures in the first layer of doped silicon, removing the masking layer, depositing a second layer of doped silicon onto the first layer of doped silicon, the second layer of doped silicon being oppositely doped to the first layer of doped silicon and etching away the first layer of doped silicon.

Before the first layer of doped silicon is etched the invention may further include the steps of performing an anisotropic wet etch on the second layer of silicon to provide at least one raised area, fusion bonding a third layer of silicon over the raised area to form at least one cavity between the second layer and the third layer. Following the step of etching away the first layer of doped silicon the invention may further include the steps of depositing a masking layer over the second layer of silicon on the side previously in contact with the first layer of silicon, patterning the masking layer to include an area of no masking at one

side of a tip, performing a release etch to remove silicon above the cavity not covered by the masking layer, and removing the masking layer.

BRIEF DESCRIPTION OF DRAWINGS

A preferred from method of the invention will be further described with reference to the accompanying drawings by way of example only and without intending to be limiting, wherein;

Figure 1A shows a layer of silicon partially covered with a masking layer;

Figure 1B shows the layer of silicon and masking layer after a wet etch;

Figure 1C shows a second layer of silicon bonded to the first layer of silicon;

Figure 1D shows the results of an anisotropic etch on the second layer of silicon;

Figure 1E shows a third layer of silicon bonded to the second layer of silicon;

Figure 1F shows a masking layer deposited onto the second layer of silicon, and

Figure 1G shows a cantilevered atomic force microscope tip formed by a release etch on the second layer of silicon.

DETAILED DESCRIPTION

Figure 1A shows a layer of silicon 1 substantially covered by a masking layer 2. The masking layer is deposited such that rectangular or square areas 7 are uncovered. These areas are those where atomic force microscope tips will be formed. The silicon is either p-type doped silicon or n-type doped silicon.

After depositing the masking layer 2 on the silicon pyramidal openings are formed in the doped silicon layer by etching with a strong base etchant, for example potassium hydroxide (KOH).

The crystal structure of silicon is a zinc blende lattice with identical atoms in each sublattice. The silicon crystal can be oriented along several planes. These planes are denoted by coordinates. For example <100>, <110> and <111> are all different planes within the silicon crystal. When etching a single crystal, certain etchants exhibit orientation dependent etch rates. In particular strong base etchants, such as potassium hydroxide (KOH), tetramethyl ammonium hydroxide (TMAH) and ethylene diamine pyrochatecol (EDP), exhibit highly orientation dependent etch characteristics in silicon.

Using a strong base etchant the etch rate in silicon is highly dependent on the direction of the crystal plane in the silicon. The <100> and <110> planes etch much faster than the <111> plane. The aspect ratio of the tip is therefore limited by the crystallographic structure of the etch pit material. Using single crystal silicon the <111> planes effectively form etch stops that enable a mould with accurate dimensions and a sharp tip to be formed. The sides of the aperture formed in the single crystal silicon forms an etch angle of 54.7° to the horizontal. Varying the mask opening sizes can easily be used to form different tip heights. The size of the apertures formed using strong base etching can therefore be controlled by the size of the aperture in the masking layer.

Figure 1B shows the results of the etching process. The etchant is ideally a strong base and may be, for example, KOH, TMAH or EDP. In a KOH etch a 45% concentration is commonly used as an etchant. Isopropyl alcohol is also sometimes added to improve the selectivity of the etch. The common temperature range of a KOH etch is between 50°C and 85°C. The temperature of the etch affects the etch rate with the etch rate increasing as the temperature increases.

Following etching with the strong base etchant the masking layer is removed using known techniques. A layer is epitaxial silicon is then deposited onto the layer of doped silicon

and fills the apertures formed by the KOH etching as shown in Figure 1C. The layer of epitaxial silicon is doped to have the opposite doping of the first layer of silicon. For example if the first layer of silicon is p-type doped then the layer of epitaxial silicon is n-type doped and if the first layer of silicon is n-type doped then the layer of epitaxial silicon is p-type doped.

Figure 1D shows the results of an anisotropic etch. This etch forms troughs and raised areas in the epitaxial silicon layer 4. In Figure 1E a second layer of silicon has been fusion bonded to the layer of epitaxial silicon. This forms cavities 8 between the two layers. Ideally the second layer of silicon has the same doping as the layer of epitaxial silicon.

Following the bonding of the two layers of silicon the first layer of silicon 1 is removed by electrochemical etch. Because the first layer of silicon and the epitaxial layer of silicon 4 are doped differently the boundary between the two layers forms a diode junction. This diode junctions acts as a stop for the electrochemical etch. This allows the first layer of silicon 1 to be removed leaving the tips formed in the layer of epitaxial silicon 4 and solves the problems of removing the tips from the mould.

Figure 1F shows the layer of epitaxial silicon 4 with cavity 8 after removal of the first layer of silicon. As masking layer 5 is deposited onto the epitaxial silicon 4. The masking layer 5 covers the atomic force microscope tips but is deposited to leave a gap after each tip.

Figure 1G shows the results of a release etch. This etches away the epitaxial silicon not covered by masking layer 5. This releases the tip from the nearest raised layer of epitaxial silicon 4 and leaves the tip cantilevered. Finally the masking layer 5 is removed to leave the cantilevered atomic force microscope tips.

Other process steps can be added to this process to form other MEMS structures such as actuators or features such as metal interconnects/bondpads.

In another embodiment the steps illustrated in Figures 1D to 1G are omitted and the first layer of silicon 1 is removed by electrochemical etch after the step of depositing the layer

of epitaxial silicon 4 shown in Figure 1C. In this embodiment the atomic force microscope tips formed using the method of the invention are not cantilevered. Again further stops can be added to this process to form other MEMS structures or other features.

Using the method of the invention atomic force microscope tips have been produced with a base of 4 × 4 microns and height of 2.82 microns. The tips produced using the method of the invention are formed of silicon and have superior stiffness and strength to tips formed of other materials such as silicon nitride, silicon dioxide etc. Atomic force microscope tips formed using the method of the invention are more uniform than those formed using chemical vapour deposition.

The foregoing describes the invention including preferred forms thereof. Alterations and modifications as will be obvious to those skilled in the art are intended to be incorporated within the scope hereof as defined in the accompanying claims.

CLAIMS

1. A method of forming silicon atomic force microscope tips including the steps of:
depositing a masking layer onto a first layer of doped silicon so that some square or rectangular areas of the first layer of doped silicon are not covered by the masking layer,
etching pyramidal apertures in the first layer of doped silicon,
removing the masking layer,
depositing a second layer of doped silicon onto the first layer of doped silicon, the second layer of doped silicon being oppositely doped to the first layer of doped silicon, and
etching away the first layer of doped silicon.

2. A method of forming silicon atomic force microscope tips as claimed in claim 1 wherein the final etch is an electrochemical etch.

3. A method of forming silicon atomic force microscope tips as claimed in claim 1 or claim 2 wherein the first layer of silicon is p-type doped silicon and the second layer of silicon is n-type doped silicon.

4. A method of forming silicon atomic force microscope tips as claimed in claim 1 or claim 2 wherein the first layer of silicon is n-type doped silicon and the second layer of silicon is p-type doped silicon.

5. A method of forming silicon atomic force microscope tips as claimed in any one of claims 1 to 4 wherein the pyramidal apertures are etched using a strong base etchant.

6. A method of forming silicon atomic force microscope tips as claimed in claim 5 wherein the strong base etchant is potassium hydroxide.

7. A method of forming silicon atomic force microscope tips as claimed in claim 5 wherein the strong base etchant is tetramethyl ammonium hydroxide.

8. A method of forming silicon atomic force microscope tips as claimed in claim 5 wherein the strong base etchant is ethylene diamine pyrochatecol.

9. A method of forming silicon atomic force microscope tips as claimed in any one of claims 1 to 8 further including the steps of:

before the first layer of doped silicon is etched performing an anisotropic wet etch on the second layer of silicon to provide at least one raised area,

fusion bonding a third layer of silicon over the raised area to form at least one cavity between the second layer and the third layer,

following the step of etching away the first layer of doped silicon depositing a masking layer over the second layer of silicon on the side previously in contact with the first layer of silicon,

patterning the masking layer to include an area of no masking at one side of a tip,

performing a release etch to remove silicon above the cavity not covered by the masking layer, and

removing the masking layer.

10. A method of forming silicon atomic force microscope tips as claimed in claim 9 wherein the third layer of silicon has the same doping as the second layer of silicon.

ABSTRACT

METHOD OF FORMING ATOMIC FORCE MICROSCOPE TIPS

The invention relates to a method for forming silicon atomic force microscope tips. The method includes the steps of depositing a masking layer onto a first layer of doped silicon so that some square or rectangular areas of the first layer of doped silicon are not covered by the masking layer, etching pyramidal apertures in the first layer of doped silicon, removing the masking layer, depositing a second layer of doped silicon onto the first layer of doped silicon, the second layer of doped silicon being oppositely doped to the first layer of doped silicon and etching away the first layer of doped silicon. Further steps may be added to form the atomic force microscope tips at the end of cantilevers.

Figure 1G

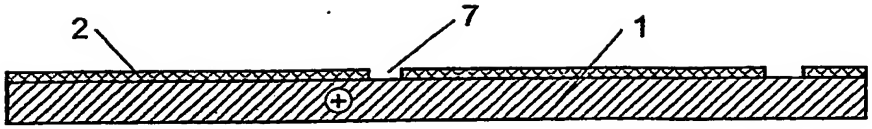

FIGURE 1A

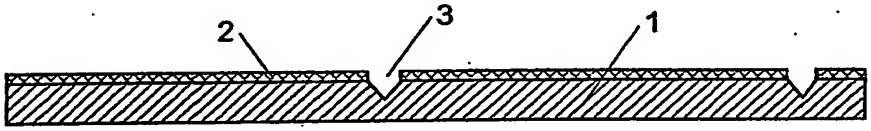

FIGURE 1B

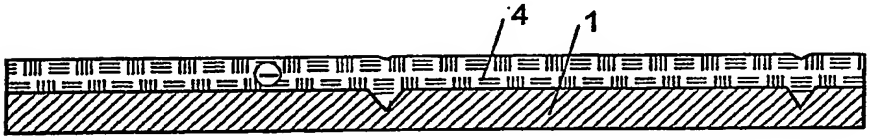

FIGURE 1C

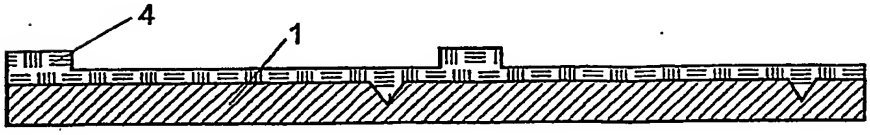

FIGURE 1D

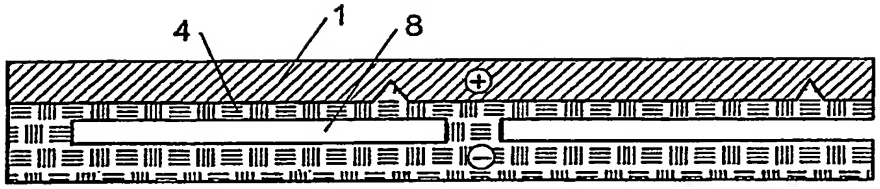

FIGURE 1E

FIGURE 1F

FIGURE 1G